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Energetic Residues from the Expedient Disposal of Artillery Propellants

Michael R. Walsh, Marianne E. Walsh, and Alan D. Hewitt

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Cold Regions Research
Engineering Laboratory

Cover photo: Expedient disposal of excess mortar propellant charges following a training exercise, Fort Richardson, Alaska, January 2006.

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Abstract: Military live-fire training missions utilizing mortars and howitzers frequently generate excess propellant charges. Disposal of this propellant is often done on-site and is referred to as expedient disposal. Investigations into energetics residues resulting from expedient disposal of propellants began in 2002 with the collection of residues inside and outside a propellant burn structure. These residues contained very high concentrations of 2,4-Dinitrotoluene, an indication that the burning process was not complete. Other informal tests were conducted, indicating the same results. In 2006 and 2008, a series of tests were conducted on snow using propellants from various mortar cartridges. In one test, 10 charges of mortar propellant were burned on snow and the residues collected and analyzed. Over 15% of the original nitroglycerin content was recovered. In 2008, two series of tests were conducted, one involving winter disposal of mortar propellants, the other summer disposal of howitzer propellants. These tests, conducted under controlled conditions, indicate that the environmental setting and climatic conditions can influence the efficiency of expedient propellant disposal by three orders of magnitude.

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Preface

This report was prepared by the U.S. Army Engineer Research and Development Center (ERDC) – Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire. Funding was provided jointly by the U.S. Army Garrison, Alaska (USAG-AK) Soil and Water Monitoring program, Gary Larson, coordinator; and by the Department of Defense Strategic Environmental Research and Development Program (SERDP) under Project ER-1481: "Characterization and Fate of Gun and Rocket Propellant Residues on Testing and Training Ranges," Dr. Andrea Leeson, Program Manager, Environmental Restoration.

This report was prepared by Michael R. Walsh, Engineering Resources Branch, and Alan D. Hewitt and Marianne E. Walsh, Biogeochemical Branch, of ERDC-CRREL. Manuscript review was provided by Dr. Sonia Thiboutot of Defence Research and Development–Valcartier, Canada, and by Chuck Ramsey of Envirostat, Fort Collins, Colorado.

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This report was prepared under the general supervision of Thomas J. Tantillo, Chief, Engineering Resources Branch; Terry Sobecki, Chief, Biogeochemical Branch; and Dr. Bert Davis, Director, CRREL.

At the time of publication, the Commander of ERDC was COL Gary E. Johnston and the Director was Dr. James R. Houston.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
inches	0.0254	meters
microns	1.0 E-06	meters
miles (U.S. statute)	1,609.347	meters
pints (U.S. liquid)	0.473176	liters
pounds (mass)	0.45359237	kilograms
quarts (U.S. liquid)	9.463529 E-04	cubic meters
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters

1 Introduction

Military ranges provide soldiers the opportunity to train using a variety of munitions. When training with artillery, a full complement of propellant charges is provided with each round and, depending on the need of the exercise, excess propellant charges may be generated. These charges contain a nitrocellulose (NC) matrix combined with energetic materials such as nitroglycerin (NG), 2,4-dinitrotoluene (2,4-DNT), and nitroguanidine (NQ). Characterization studies conducted at various firing points (FP) have demonstrated that propellants are not completely consumed during live-fire exercises (USACHPPM 2000; Ogden EES 2000; Jenkins et al. 2001; M.E. Walsh et al. 2004, 2007; Dubé et al. 2006; Thiboutot et al. 2007). We thus hypothesized that significant energetic residues would be generated by the open burning of excess propellant charges at these training sites.

In June 2002, Marianne Walsh and Arthur Gelvin conducted a test to determine if measurable amounts of energetics remained after burning of excess M1 propellant from 105-mm howitzer cartridges in a sand-filled burn pan (Walsh et al. 2004). The measured concentration of 2,4-DNT in the sand collected from within the burn pan following the tests was 2.3 g/kg and the concentration of 2,4-DNT found in soil samples collected on the ground downwind of the burn pan was 0.12 g/kg. In addition, concentrations of 2,6-DNT of approximately 5% of the 2,4-DNT were also found. The obvious conclusion is that the open burning of excess propellants will generate significant amounts of energetics residues.

The State of Alaska has listed 2,4-DNT as a Class 2 carcinogen. The U.S. Army Alaska was thus interested in knowing the possible extent and sources of this compound on their training ranges. In addition, a Strategic Environmental Research and Development Program project (ER-1481) under Dr. Thomas Jenkins of the U.S. Army Engineer Research and Development Center — Cold Regions Research and Engineering Laboratory (ERDC–CRREL) was investigating propellant residues from the use of munitions. Leveraging both interests, a series of tests were performed starting in the winter of 2006 in Alaska to estimate the deposition rate of energetics residues resulting from the open burning of excess propellants.

2 Field Test Methods

2.1 Field sites

The project's three test series were conducted at field sites within either the Eagle River Flats Impact Area (ERF) of Fort Richardson, Alaska (FRA), or at Observation Point 7 (OP 7) in the Donnelly Training Area (DTA) near Fort Greely, Alaska.

The first series of tests occurred January 2006 at Firing Point (FP) Upper Cole (M.R. Walsh et al. 2006). FP Upper Cole is an open, gravelly area atop a bluff overlooking ERF. At the time of the test, it was covered with 25–35 cm of snow (Figure 1). The second series of tests were conducted from February through July 2008 in a basin area adjacent to the open burning/open detonation pad at ERF (Figure 2). The basin was used in the mid-1990s as a containment structure and settlement area for a dredge operation conducted at ERF. Thus, soil in the basin is a peaty loam liner over the underlying native, compacted, unsorted gravel. The 716th Explosive Ordnance Disposal (EOD) detachment at Fort Richardson has used this site on occasion to dispose of unexploded ordnance found in ERF. Detonation of munitions in the basin had not occurred that winter and the nearest legacy (pre-snowpack) detonation point is over 30 m from the test site. None of these prior detonations involved munitions containing materials addressed in the propellant burn tests. At the time of the tests in February 2008, snow depth was 40 cm. Sampling in 2008 at this site occurred once in the winter and twice over the course of the following summer. The final test included in this report was conducted at OP 7 in July 2008 (Figure 3). OP 7 occupies the top of a bluff looking south over the Delta River. The soils are glacial, unsorted till. For the test, clean sand was spread 40-cm wide x 1.8-m long x 4-cm deep over the ground near the existing burn pan to separate our tests from the existing ground contamination.

a. Winter 2006

b. Spring 2006

Figure 1. Firing Point Upper Cole adjacent to Eagle River Flats at Fort Richardson, AK.

Figure 2. Basin adjacent to the Eagle River Flats Impact Area.

Figure 3. Propellant disposal area at Observation Point 7, Donnelly Training Area, AK. Burn pan is in center of image.

Propellants

The tests used excess propellant charges from three different munitions. In the first series of tests, we burned 10 M185 propellant charges from M301A3 81-mm illumination rounds. Each charge contained 13.3 g of M9 double-base propellant. For the second series of tests, 10 to 11 M230 propellant charges from M933 120-mm high-explosive (HE) rounds were burned for each of the three different physical conditions, all with the same meteorological conditions. Each charge contained 130 g of double-base propellant. For the third series of tests, five sets of Charge 6 and Charge 7 propellant bags containing M1 single-base propellant were burned for each condition. Table 1 lists the energetics constituents for each test. Appendix A contains complete munitions data for these tests.

Table 1. Energetic constituents for propellants used during tests.

Test	Propellant	Constituent	Weight (g)
81-mm burn (10 M185 charges)	M9 (each)		13.3
		NC	7.65
		NG	5.31
		Other	0.34
120-mm winter burn (2 x 11, 1x10 M230 charges)	M45 (each)		130
		NC	112
		NG	13
		Other	5
105-mm summer burn (2 x 5 sets of Increment 6 & 7 M67 charges)	M1 (per set of 2)	Charges 6 & 7	655
		NC	557
		DNT	65
		Other	33

2.2 Tests

Our tests were conducted in association with the 1st Battalion, 501st Parachute Infantry Regiment, and the 716th EOD detachment, at FRA; and an artillery battery training at DTA. All tests involved standard-issue live munitions. In all tests, a few unburned grains were collected prior to the tests for analysis and confirmation of propellant formulation.

2.2.1 January 2006 test: Mortar propellants on snow

In mid-January 2006, our first controlled field-expedient burn test of a mortar propellant was conducted. The propellant was excess to the requirement for the training mission and was originally issued with 81-mm M301A3 illumination rounds. No background surface snow sample from the test area was collected because the area had previously been sampled as part of a different test, and background propellant residue levels were known. Ten propellant bags were piled on the snow surface and initiated with a butane lighter (Figure 4). Following the burn, all the surface snow in the affected area (M.R. Walsh, M.E. Walsh, and Ramsey 2007) was collected down to clean snow by following standard snow sampling practices developed at CRREL (M.R. Walsh et al. 2007). A 30-cm annulus surrounding the main sampled area was also collected for analysis. All samples were placed in clean polyethylene (PE) bags for transport to the field lab for processing.

Figure 4. 81-mm propellant burn test on snow.

Figure 5. 81-mm propellant burn residues.

2.2.2 February 2008: Disposal of M45 mortar propellants under various conditions

The 120-mm burn test was conducted in association with blow-in-place testing of high-explosives cartridges on 14 February 2008. Thirty-two propellant charges were separated from their cartridges prior to detonation. Three setups were assembled. The first setup consisted of 11 charges placed on the snow surface (Figure 6). For the second setup, the 40-cm deep snow cover was removed from a 30- x 30-cm area to expose the frozen ground (Figure 7); 11 charges were then placed in the center of the cleared area. For the third test, a stainless steel bowl 27 cm across at the bottom, 34 cm across at the top, and 11 cm deep was pressed into the snow surface up to its rim and 10 charges were placed in the center bottom of the bowl. For all three tests, one of the charges was cut open enough to insert a section of M700 time-blasting fuze, which shot a delayed burst of flame into the charges to ignite the propellant.

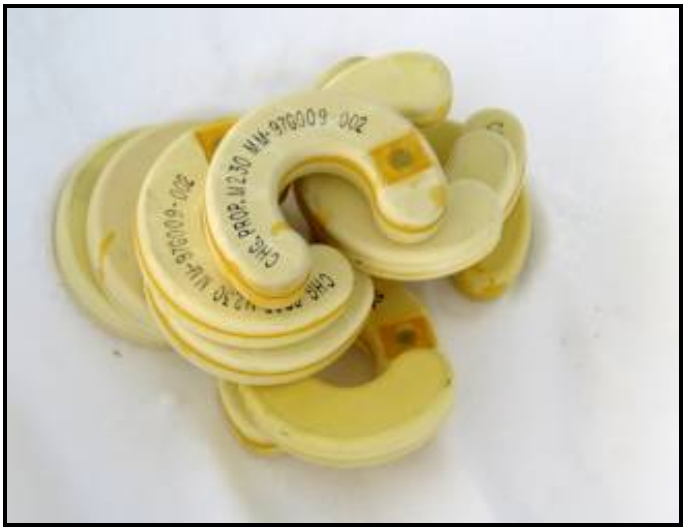

Figure 6. 120-mm propellant burn tests, charges on snow.

Figure 7. 120-mm propellant burn tests, charges on frozen soil.

Following the test burns, the residues within the bowl were collected (Figure 8) and bagged and the bowl itself placed in a clean PE bag. A 1-m diameter area of the snow surrounding the bowl location (Figure 9) was then sampled to a depth of 2.5 cm and sealed in a PE bag for further processing and analysis (see next section). The other two test locations were marked and left for sampling the following spring.

Figure 8. Aftermath of 120-mm propellant burn, residues in burn bowl.

Figure 9. Aftermath of 120-mm propellant burn, residues surrounding bowl after burn.

2.2.3 June and July 2008: Sampling of M45 burn points

In early June 2008, the two 120-mm propellant burn locations (one with snow and the other with snow removed to the frozen ground) were sampled for propellant residue. First, each location was visually inspected. Both locations had intact propellant grains on the surface (Figure 10). Individual 3-cm diameter cores were obtained to a depth of 2.5 cm within the center portion of the burn points for subsequent laboratory analysis. Then, all of the soil within the top 2.5 cm that had visible grains at each burn point was collected using a stainless steel scoop and placed in a PE bag. A 1-m diameter area was marked at each burn point using survey tape

(Figure 11) and a 50-increment sample was obtained outside the previously sampled area using a 4.75-cm corer to a depth of 2.5 cm. Both burn locations were sampled in this manner. All samples were shipped to the analytical lab at Hanover, NH for chemical analysis.

a) February 2008 following burn.

b) June 2008 prior to first sampling.

c) June 2008: Recovered unburned propellant.

d) July 2008 prior to second sampling.

Figure 10. M45 mortar propellant grains after burn tests.

Figure 11. Sampled area: 120-mm prop burn on frozen ground (June 2008).

Based on the results of analyses from the June sampling, further sampling was conducted at the snow and frozen ground propellant burn sites in July 2008. At each burn point, a 0.5–1.0 m annulus and a 1.0–1.5 m annulus was marked with survey tape (Figure 12). Within each annulus, duplicate multi-increment samples were taken. Samples were collected using a 3-cm diameter CRREL-designed coring tool that was set to a depth of 2.5 cm. The number of increments per sample ranged from 20 to 26. Closer examination of the center of the burn points revealed that some grains were missed in the June sampling, so these grains and the underlying soil were collected. Finally, three soil profiles were taken below the locations of the July propellant grains in 2-cm increments (lifts) through the peaty loam to the underlying gravel (Figure 13). All samples again were shipped to the analytical lab at Hanover for final processing and analysis.

Figure 12. July resampling of 120-mm mortar prop burn sites, showing sampling areas.

Figure 13. July resampling of 120-mm mortar propellant burn sites, showing depth samples.

2.2.4 July 2008 test: Howitzer propellants on soil

The final series of tests was conducted in July 2008. An artillery unit was training with 105-mm howitzers at DTA while we were at the site, and we were able to obtain 10 Charge 6 and 10 Charge 7 propellant bags to use in a burn test. Two separate cells, consisting of clean sand (1.8-m long x 40-cm wide x 4-cm deep), were placed over the ground. One test cell was wetted, and five Charge 6 and five Charge 7 propellant bags were lined up alternately in the center of the cell. The end bag was cut and the propellant grains spread out in a line for about 5 cm. The end grains were then lit with a butane lighter and the line of charges proceeded to burn. For the

second test, the 10 bags were lined up as above, only this time on the dry sand cell, and ignited by lighting the end bag with the lighter. For both test cells, the burn areas were completely sampled to a depth of about 1.5 cm, followed by sampling outside the burn areas and sampling below the burn areas (Figures 14c and 14d). Each sample was placed in a clean PE bag for later processing and analysis at the analytical lab in Hanover.

a. Start of burn b. Propellant burning on wet sand

c. Residues after burn d. Depth samples

Figure 14. Burning of 105-mm howitzer propellants.

3 Sample Processing and Analysis

3.1 Sample preparation

3.1.1 Snow samples

Snow samples were melted in a nearby field lab where they were vacuum filtered to separate the solids from the aqueous fraction. The 90-mm ø glass microfiber filters (Whatman Grade GF/A) containing the solid residues were stored in refrigerated 120-mL clean amber jars (one sample per jar). A 500-mL aliquot of the aqueous fraction was passed through a solid-phase extraction cartridge (Waters Porpak RDX Sep-Pak, 6 cm3, 500 mg) to pre-concentrate the energetics. For the January 2006 tests, the cartridges were wrapped in aluminum foil, bagged, and placed in a refrigerator for storage prior to shipment overnight to the analytical chemistry laboratory at CRREL for final processing and analysis. For the February 2008 test, the cartridge was eluted with 5 mL of acetonitrile (AcN), resulting in a 100:1 concentration of the analytes. The soot samples and a 3.5-mL aliquot of the solid phase extracts were shipped overnight to the analytical laboratory at CRREL for final processing and analysis. Energetics were extracted from the solid residues captured on the filters using AcN by shaking each sample with the solvent for 18 hours.

3.1.2 Burn bowl samples

Cleaning of the bowl from the 120-mm propellant burn test proved to be quite a challenge. The loose, solid residue (not adhered to the bowl) was weighed in a tared 250-mL wide mouth jar (Figure 15). A 50-mL aliquot of AcN was added to extract the NG from the residue. Much of the AcN was absorbed by the residue, so an additional 50 mL of AcN was added. The jar was placed on a platform shaker and shaken at 150 rpm for 18 hours prior to analysis.

Figure 15. Processing of the burn bowl residues, loose residues from bowl.

Figure 16. Cleaning the char from the burn bowl.

The bowl had charred residue adhering to the bottom and sides (Figure 16). To extract the NG from the residue, the following sequential procedure was used:

1. 50-mL aliquots of AcN were added to the bowl and the bowl swirled to allow contact between the solvent and the residue that was fixed to the inside surfaces of the bowl. Each aliquot, which was very yellow, was then poured into a 250-mL graduated cylinder until a 200-mL volume of AcN was obtained for analysis by high performance liquid chromotography (HPLC).
2. A metal spatula was used to scrape all inside surfaces of the bowl (Figure 16), and the solid residue was transferred to a 120-mL wide mouth amber jar. A 20-mL aliquot of AcN was added to the jar and the

contents shaken for 1 hour. Then, one drop of the extract was tested for the presence of NG using the EXPRAY kit (as described below). The EXPRAY indicated that the concentration of NG was high, so an additional 20-mL of AcN was added to the jar and the jar was shaken overnight (~ 18 hr).

3. More 50-m aliquots of AcN were used to rinse the bowl until the solution was colorless. The final sample volume totaled 180 mL.
4. A 50-mL aliquot of AcN was added to the bowl and the inside of the bowl was wiped with a glass fiber filter. The filter was squeezed to remove as much solvent as possible and placed in a 250-mL wide mouth jar. The AcN was poured into a 250-mL graduated cylinder. The same process was repeated with more AcN, and a second glass fiber filter used to wipe the bottom and sides of the bowl. The bowl was rinsed until a 200-mL volume of AcN was collected in the graduated cylinder. The AcN was then poured into the jar with the filters.
5. Finally, additional 50-mL aliquots of AcN were used to rinse the inside surfaces of the bowl. All AcN remaining after the analysis of the sample was disposed of by following strict laboratory standards.

3.1.3 Soil samples

At the lab, the >2-mm fraction was sieved out of each sample and retained. The < 2-mm fraction was then ground, subsampled, and analyzed according to EPA SW-846 Method 8330B (USEPA 2006). The >2-mm fraction was extracted using whole sample extraction and analyzed.

Propellant grain composition

To determine the actual amount of NG in the double base grains of the M9 and M45 propellant and the amount of 2,4-DNT in the single-based M1 propellant, approximately 100 mg of unburned grains of each type of propellant were dissolved in AcN. The M45 grains that were isolated from cores taken in June at the frozen ground and snow-covered burn points were also dissolved in AcN. The masses of NG or 2,4-DNT were determined by HPLC analysis.

3.2 Analytical methods

3.2.1 EXPRAY

An EXPRAY kit (Plexus Scientific Corporation) was used to test for the presence of NG or 2,4-DNT in the AcN extracts and to estimate the dilu-

tion needed prior to HPLC analysis (Bjella 2005). (Note: this test also responds to NC.) One drop of each extract was placed on the paper supplied with the EXPRAY kit. Then the paper was sprayed sequentially with two reagents. The first reagent is alkaline and forms a blue-green product if 2,4-DNT is present. The first reagent in combination with the second reagent forms nitrate ions from NG, resulting in a pink colored product as a result of Griess reaction. The color intensity is proportional to the concentration of 2,4-DNT or NG (and other nitroaromatic, nitrate esters, and nitramines, if present) in the AcN aliquot, with a more intense color corresponding to a higher analyte concentration.

3.2.2 HPLC

Prior to analysis, each extract was diluted with AcN based on the intensity of the color from the EXPRAY test so that the injected concentration would be less than 10 mg/L. The AcN was then mixed with reagent-grade water (1:3 v/v) and filtered through a Millex-FH filter unit (Millipore, PTFE, 0.45 µm).

Determinations were made on a modular system from Thermo Electron Corporations composed of a Finnigan SpectraSYSTEM Model P4000 pump, a Finnigan SpectraSYSTEM UV2000 dual wavelength UV/VS absorbance detector (cell path 1 cm), set at 210nm (to detect NG) and 254 nanometers (nm) (to detect other energetics), and a Finnigan SpectraSYSTEM AS300 autosampler. Samples were introduced with a 100-µL sample loop. Separations were achieved on a 15-cm X 3.9-mm (4-µm) NovaPak C8 column (Waters Chromatography Division, Milford, Massachusetts) at 28 °C and eluted with 1.4 mL/min of 15:85 isopropanol/water (v/v).

Calibration standards for NG and 2,4-DNT were prepared from analytical reference materials obtained from Restek Corporation (Bellefonte, PA). The concentration of each analyte was 10 mg/mL in AcN in the solutions used to calibrate the HPLC-UV.

4 Results

4.1 NG content of M9 and M45 propellant and 2,4-DNT content in M1 propellant: Unburned state

Unburned propellant grains were analyzed to determine if the analytes of interest were present in specified concentrations. Each type of propellant was found to be within military specifications for NG or DNT content (Table 2). The analytically derived mass percentages were used to better estimate the energetics residue resulting from our tests.

Table 2. Analysis results for propellant grains prior to burn tests.

Propellant	Actual Mass of Grains (mg)	Mass of Analyte Recovered (mg)	Analyte Mass %	Military Specified Analyte %
M9	117	46 (NG)	39%	40±1.5%
M45	114	12 (NG)	10%	10±2%
M1	115 (one grain)	11 (DNTs)	9.7%	10±2%

4.2 Winter tests

4.2.1 M9 propellant

The results of the analysis of the 81-mm mortar cartridge propellant burn are presented in Table 3. Characterization of the site prior to the test indicated a residue level of <200 µg NG / m^2 from mortar firing during the previous two days. The area influenced by the burn test was less than 1 m^2. Because of the small quantity of charges involved in the test, the propellant burned only a few centimeters into the snow. Approximately 870 mg (1.7 %) of the NG in the original charges was recovered from the sampled area. This is equivalent to about 87 mg NG per charge. The background concentration of NG due to the firing exercise was insignificant, three orders of magnitude less than the final concentrations of the snow samples following the burn test.

Table 3. Results of analyses for NG following disposal of M185 propellant charges on snow.

Sample	DU† Size (m^2)	Recovered Mass (mg)	Recovered Mass (%)
Background*	0.56	0.11	—
Burn Point	0.063	840	1.6%
Annulus	0.50	33	0.06%

*Background mass estimated from background concentration of 200 µg/m^2

†Decision Unit (Total area from which sample was taken)

4.2.2 M45 propellant

As discussed earlier, the 120-mm mortar cartridge propellant burn experiment in February 2008 involved several activities. These included the immediate post-burn sampling of the snow at the site as well as processing of the burn bowl residues, the initial soil sampling in June 2008, and the follow-up soil sampling in July 2008. Both the June and July samplings addressed the snow and frozen ground burn residues.

4.2.2.1 NG remaining in the burn bowl

The burn bowl and associated loose, solid residues were processed as described in Section 2 of this report. The mass of loose residues within the bowl contained 2.3 mg of NG. Residues that were scraped from the bowl contained 23 mg of NG. The bowl cleaning process yielded an additional 48 mg of NG, with 0.26 mg NG recovered with the final rinse (Appendix B). The snow surrounding the burn bowl contained 200 mg of NG. The total mass recovered was 270 mg, 73% of which was found outside the burn bowl. The per-charge NG residues are thus 27 mg/charge, or 0.21% of the original load.

4.2.2.2 NG remaining from the burns on snow and frozen ground

The mass of NG remaining after the snow and frozen soil burns indicated that large quantities of propellant remained after both experiments. The results are divided into three zones for both experiments. The center zone encompasses the burn location and the surrounding area out to 0.5 m. This zone contained the recovered propellant grains. The other two zones were the two annuli surrounding the central areas. Estimates of the mass per charge and percentage of mass per charge for all three experiments with M45 propellant, including the burn bowl, are shown in Table 4. The residues from the propellant that was burned on the snow pack contained

an estimated 18% of the initial NG mass, indicating a very inefficient burn. Residues from the burn on frozen ground had 5% of the initial NG mass. Both of these unconfined burns left numerous propellant grains on the soil surface that are included in the totals. The burn bowl experiment, as stated above, had residues containing 0.21% of the original mass of NG. The relative percent differences (RPDs) for the four annular samples taken around the snow and frozen ground burns averaged 49%, higher than we like to see, but not unusual when trying to measure areas containing a few propellant grains kicked out during a deflagration process. Appendix C contains the analytical data leading to these results.

Table 4. Results of M45 propellant burn experiments.

Sample Description	NG (mg)
Burn Bowl	
Within Bowl	73
Residue on snow surrounding bowl	200
Total NG Mass Remaining for Bowl Burn	270
Initial NG Mass in 10 M45 Charges	130,000
NG Recovered (%)	0.21%
Frozen Soil Burn	
Center 0.5 m radius	7,200
Annulus 0.5 to 1.0 m	140
Annulus 1.0 to 1.5 m	<10
Total NG Mass Remaining for Frozen Soil Burn	7,340
Initial NG Mass in 11 M45 Charges	140,000
NG Recovered (%)	5.2%
Snow Burn	
Center 0.5 m radius	22,300
Annulus 0.5 to 1.0 m	2,100
Annulus 1.0 to 1.5 m	560
Total NG Mass Remaining for Snow Burn	25,000
Initial NG Mass in 11 M45 Charges	140,000
NG Recovered (%)	18%

4.2.2.3 Soil depth profiles from burns on snow and frozen ground

Propellant grains from the tests conducted in February remained on the ground through June and, for some not collected in June, they remained on the ground until follow-up sampling in July. Three soil profile samples were taken to determine if any transport had occurred during the initial snowmelt and subsequent summer months. One profile was taken in the center of each burn location that was sampled in June, and a third was taken in July beneath a cluster of grains remaining after the June sampling event at the snow burn location. Results are shown in Table 5 and Figure 17.

The NG concentrations were in the µg/g range for the shallowest soil samples. The mass that is present in these soil samples was small compared to that in the surface 1.5- or 2.5-cm bulk samples that were taken above the profile locations. The profile taken in July beneath the cluster of grains at the snow burn location gives an extended view of the effect of propellant weathering. A comparison can be made between this area and the area of the same burn location that was sampled in June. In July, the soil profile taken below the recently removed grains and surface soil contained 31% of the NG mass estimated in the surface and grains (7.4 mg vs. 24 mg). In June, it was 1.2% (0.6 mg vs. 50 mg). Although this is only a rough estimate of the effect of the additional weathering of the surface grains and residues, it indicates that leaching of NG into an organic surface soil will occur.

Table 5. Results of analyses of soil column profiles for M45 propellant burn.

Sample Description	NG Soil Concentration (µg/g)	Total NG Recovered (mg)
Frozen Soil Burn – Center of pit		
Original surface sample (Top 2.5 cm)	990	16*
0–2 cm from new surface	52	2.2
2–4 cm	<0.1	
4–6 cm	<0.1	
6–8 cm	<0.1	
8–10 cm	<0.1	
Total mass for profile samples		2.2

Sample Description	NG Soil Concentration (µg/g)	Total NG Recovered (mg)
Snow Burn – Center of pit		
Original surface sample (Top 2.5 cm)	3,100	50*
0–2 cm from new surface	23	0.60
2–4 cm	<0.1	
4–6 cm	<0.1	
6–8 cm	<0.1	
8–10 cm	<0.1	
10–12 cm	<0.1	
12–14 cm	<0.1	
Total mass for profile samples		0.60
Snow Burn – Below grain mass		
Original surface sample (Top 1.5 cm)	2,500	24*
0–2 cm from new surface	180	5.8
2–4 cm	46	1.3
4–6 cm	9.0	0.30
6–8 cm	<0.1	
8–10 cm	<0.1	
10–12 cm	<0.1	
12–14 cm	<0.1	
Total mass for profile samples		7.4

Note: Original surface samples (top 2.5 and 1.5 cm) contained propellant grains

*Estimated for equivalent sample area as taken for profile lifts (2 cm x 2 cm).

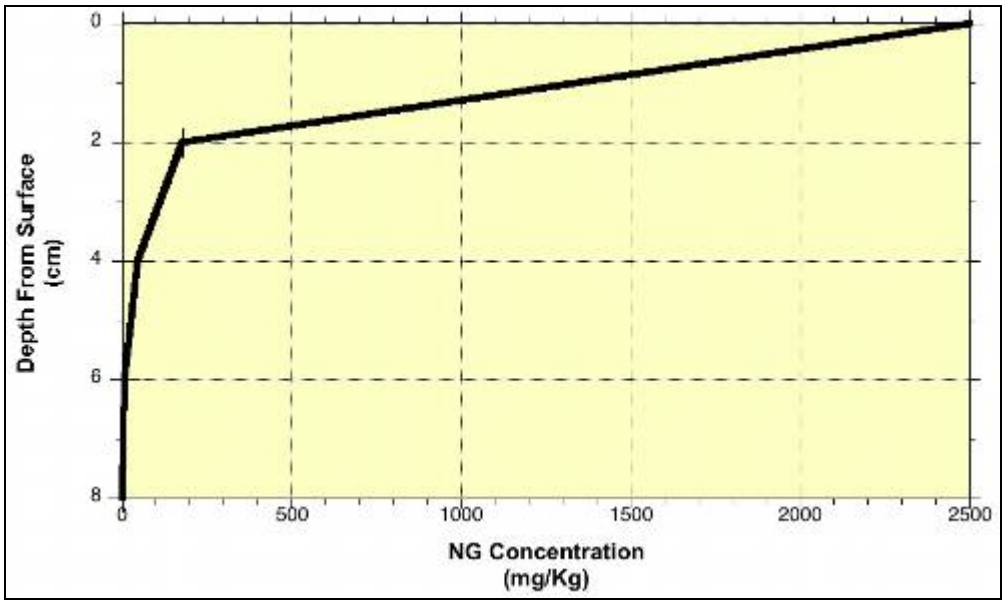

Figure 17. Graph of NG concentration as a function of depth of the soil profile taken beneath unburned M45 propellant grains, July 2008.

4.2.2.4 NG in unconsumed propellant grains

Finally, we analyzed the mass of NG in grains remaining on the soil surface. In June, grains were isolated from three core samples from the snow burn and frozen ground burn tests (3-cm ø). The grains were counted and analyzed for percent NG remaining. Table 6 shows the results of the analyses. The NG mass remaining in the weathered grains was 56% of the mass expected for unburned grains, based on laboratory analyses of propellant grains collected prior to the burn test (Table 2; Appendix D).

Table 6. Results of analyses of propellant grains collected from sample cores.

Sample	# Grains	Theoretical NG Mass (mg)†	NG Mass Recovered (mg)	% Mass Recovered
Frozen Ground	977	410	230	56%
Snow Burn	741	310	170	55%

† Based on the analysis that each grain contains 10.4% NG on average and the grains are 4 mg each.

It is interesting to note that the mass of NG recovered from a single 3-cm ø core sample can be quite high. Six 2.5-cm deep core samples were examined for the number of intact grains on the surface, the NG content in the weathered grains, and the concentration of NG in the soil (Table 7). The recovered NG averaged 95 mg per core sample, with sample concentrations averaging 5.4 mg/g. This average concentration is almost three orders of magnitude higher than the concentrations found on a nearby firing point heavily used by units training with the 120-mm mortar using M45 propellant at Fort Richardson (8.7 µg/g - Walsh, M.E., et al. 2007). The effect of a single core or increment containing burn point propellant grains can have a pronounced effect on a multi-increment sample collected to characterize a firing point. The effect on a discrete sample is even greater.

Table 7. Results of analyses of core samples containing propellant grains.

Core #	Grains in Sample	NG in Grains (mg)	Soil Mass (g)	NG Conc. in Soil (µg/g)	NG in Soils (mg)	Total NG (mg)	NG Conc. in Sample (µg/g)
1-Frozen Ground	366	84	17	2,500	42	120	6,800
2- Frozen Ground	351	84	16	1,200	19	100	6,000
3- Frozen Ground	260	59	19	1,200	22	81	4,100
1-Snow Burn	330	64	16	2,700	45	110	6,300
2- Snow Burn	140	37	18	1,400	25	62	3,400
3- Snow Burn	271	67	16	1,300	21	89	5,600

4.3 Summer tests

4.3.1 M1 propellant

Samples for the two test burns utilizing M1 single-based howitzer propellant were processed and analyzed in two steps. The <2-mm fraction was ground using a ring-and-puck mill, sub-sampled using the multi-increment technique (n≈40), extracted with AcN, and analyzed. The >2-mm fraction was extracted using whole-sample extraction and then analyzed (Appendix C). A summary of the results is given in Table 8. From this table, the total recovered DNT is 3,100 mg for the burn on dry sand and 3,300 mg for the burn on wet sand. Of these totals, ≈18% of the mass is from the >2 mm fraction. For the dry burn, 87% of the mass was found in the initial sampling of the plume, 13% was recovered from the subsurface samples, and <0.5% was recovered from outside the initial sample area. For the wet burn, the corresponding averages were 73%, 26%, and <0.5%, respectively. Combined DNT in the residues is 0.94% of the original load for the dry burn and 0.99% for the wet burn.

The background sample taken for the 105-mm M1 propellant burn test showed a slight amount of analytes: <2 mg of 2,4-DNT and <0.1 mg 2,6-DNT in a 430-g sample. The source of these analytes was found to be from cross-contamination due to co-storage of the background and residues samples. The background levels for DNT are thus <0.07% for both burns.

Table 9 summarizes all the propellant burn tests conducted for this report. Only the final total estimated mass is given for each test. These totals in-

clude the results of the soil profiles and both June and July surface sampling for the 120-mm mortar tests on snow and frozen ground.

Table 8. Results of analyses of M1 propellant burn tests.

Sample	Fraction	Recovered Mass: 2,4-DNT (mg)	Recovered Mass: 2,6-DNT (mg)	Total Recovered Mass: DNT (mg)	Total % Mass Recovered: DNT
Background	<2 mm	1.6	0.064	1.7	
	>2 mm	0.37	0.013	0.38	
	Totals	2.0	0.077	2.1	
Dry Burn	<2 mm	2,400	103	2,500	(81% of total)
	>2 mm	570	28	600	(19% of total)
	Totals	3,000	130	3,100	0.94%
Wet Burn	<2 mm	2,600	98	2,700	(82% of total)
	>2 mm	550	27	580	(18% of total)
	Totals	3,100	130	3,300	0.99%

Table 9. Summary of test results.

Test	Estimated Total NG Mass in Residues	Percent original NG Mass in Combined Charges
Winter Tests		
81-mm Mortar		
Snow surface	870 mg	1.7%
120-mm Mortar		
Burn bowl	270 mg	0.21%
Frozen soil	7,300 mg	5.2%
Snow surface	25,000 mg	18%
Summer Tests		
105-mm Howitzer		
Dry sand	3,100 mg	0.94%
Wet sand	3,300 mg	0.99%

Over the course of these experiments, many QA procedures were conducted to ensure the quality of the data. Replicate logs were maintained for all samples from the point of collection through the final analyses. Background (baseline) samples were taken, where necessary, to ensure that any background contamination was not significant. Multi-increment sampling was carried out when sampling the larger decision units. Where discrete (whole area or bulk) samples were taken, subsurface

samples and samples outside the burn areas were obtained in most cases. In the processing lab, replicate subsamples of the ground samples and the snow sample aqueous fractions were obtained. Blanks and spikes were run through the processing equipment to check for cross contamination and to verify procedural efficacy. Whole-sample extraction was done on the >2-mm fraction for the 105 propellant burn tests. In the analytical lab, blanks and spikes were run to verify instrument output. The lab replicates of ground soil and of melted snow samples were processed and analyzed to verify repeatability. All QA procedure results indicate sampling and data fidelity.

5 Discussion

The impact of environmental factors on the efficacy of field-expedient disposal of excess propellants from training exercises is quite significant. The mass remaining following the burning of the M45 propellant on snow and on frozen ground surrounded by snow was much larger than expected, based on the small-quantity test conducted in 2006 with M185 mortar propellant. However, the original test did not generate the heat and violence of burning seen with the larger-quantity tests. There is a phenomenon that occurs that our Canadian colleagues term the "popcorn effect" in which gasses generated by the deflagrating propellant will eject material during the disposal process. This was evident during the burn bowl test in which nearly 75% of the recovered energetics fell outside the bowl. Ejected, unburned propellant grains can constitute a cumulative environmental hazard, especially with propellants that contain DNT, RDX, or heavy metals such as lead. We often find propellant grains scattered about fixed burn points, even those with burn pans and especially when improper disposal methods are employed. The presence of propellant grains can also pose health and security risks. When ignited, even a small amount of propellant will burn furiously, posing a risk to the unaware. Larger quantities pose a security risk as well, because confined propellants can detonate when initiated.

6 Conclusions

This set of experiments demonstrates that environmental factors and climatic conditions will have a strong effect on the efficacy of the field-expedient disposal of excess propellants. Results showed that the use of a properly designed and utilized burn pan is critical in the disposal of propellants in winter, especially when snow cover is present. The presence of large quantities of unburned propellants at disposal sites can constitute both an environmental hazard and a security risk.

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Abbreviations, Acronyms, and Annotations

2,4-DNT	2,4-Dinitrotoluene
2,6-DNT	2,6-Dinitrotoluene
AcN	acetonitrile
CRREL	Cold Regions Research and Engineering Laboratory
DNT	dinitrotoluene
DoD	U.S. Department of Defense
DTA	Donnelly Training Area
DU	decision unit
EOD	Explosive Ordnance Disposal
EPA	Environmental Protection Agency
ER	Environmental Restoration
ERDC	Engineer Research and Development Center
ERF	Eagle River Flats
FP	Firing Point
FRA	Fort Richardson, Alaska
HE	high explosives
HPLC	high performance liquid chromotography
NC	nitrocellulose
NG	nitroglycerin
NQ	nitroguanidine
OP	Observation Pint
PE	polyethylene
QA	Quality Assurance
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine
RPD	relative percent difference
SERDP	Strategic Environmental Research and Development Program
SW	solid waste
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
UV	ultraviolet

Appendix A: Munitions Data

The following information on the rounds used in the propellant burn tests was taken from munitions packing crates at the site of the training mission or test. All munitions are standard issue for live-fire training and are commonly used by the military. No lot data was obtained for the 105-mm munitions, although a loaded date was obtained and is listed in Table A-1. Propellant data can be found in Table 1, Section 2.

Table A- 1. Munitions data.

NSN	DODIC	Nomenclature	Lot No.	Drawn for tests
1315001437048	C226	Cartridge, 81-mm IL, M301A3, w/Fuze, Time, M84A1	LOW85C108013	61*
1315013431941	C623	Cartridge, 120 MM HE, M933, W/Fuze, PD, M745	MM97K025002	8
1315000284857	C445	Cartridge, 105MM HE M1 Dualgran	(Loaded Mar 2002)	10**
*Drawn for training mission. **Number of rounds from which propellant bags were used in tests.				

Mortar rounds and howitzer rounds are packaged differently. There are variations and differences in the general rules of their packaging, the following descriptions give a general guide for how these munitions are handled. Mortar rounds are packed as cartridges and howitzer rounds are packed as projectiles. The difference is in how the propellant is handled. A mortar cartridge can often be fired “out of the box” without the addition of propellant.

Each mortar round is assembled with an integral ignition cartridge in the tail assembly, capable of ejecting the round out of the mortar tube and arming most fuzes. The cartridges come with additional propellant charges attached to the tail assembly. The number of charges can be adjusted (by removal) to vary the range of the round. Charges not used are excess and are disposed of following a training mission either by burning on the ground (or snow surface) or in a burn pan.

The howitzer rounds are handled differently. The 105s are composed of a projectile, a fuze (sometimes attached), a supplementary charge in the fuze well (optional based on the fuze type), a brass cartridge case, and propellant charges. All elements are separate components. The charges consist of

a series of bags containing varying amounts of propellant, with the first two charges containing single-perforated cylindrical grains and the remaining five containing 7-hole, multi-perforated, cylindrical grains. As above, the charges are adjusted to get the required range for the projectile. They are used in the order of the charge numbers, with the lower charge numbers used prior to the higher charge numbers for the standard charge load. Charges not used are excess and are disposed of (by burning, as described previously) at the end of the training exercise. For our tests, we utilized five each of Charges 6 and 7, containing 250 g and 408 g of multi-perforated M1 propellant respectively. Thus, each test incorporated $5 \cdot (250+408\text{g}) = 3.3$ kg of multi-perforated M1 propellant containing 10 ± 2.0% DNT.

Appendix B: Results of Burn Bowl Analyses for NG

Processing of the burn bowl residues was a multi-step process, as outlined in this report's Section 3 (Sample Processing and Analysis). The following table (Table B-1) presents the results from analyses for each step of that process. As pointed out in the Section 4 (Results), the final rinse of the bowl contained very little NG, two orders of magnitude less than the first rinse and less than 0.1% of the total recovered NG. This is a good indication that very little NG was missed in processing residues in the bowl. Results from the snow samples taken outside the bowl are also included in this table.

Table B- 1. Results of burn bowl test analyses.

Sample	NG Mass (mg)
Contents of bowl	
First rinse	44
Second rinse	2.4
Third rinse	0.59
Fourth rinse	0.26
Loose solid residue (11.8 g)	2.3
Adhered solid residue (5.17 g)	23
Subtotal	73
From snow outside the bowl	
Snowmelt	7.7
Soot	190
Subtotal	200
Total – All sources	270

Appendix C: M45 Propellant Analytical Data and Results

Tables C-1 and C-2 contain analytical data and results for the samples run for the winter test burning of M45 propellant. In these two tables, data is divided into the different sampling events and tasks. Some samples were rerun to verify results. Table C-3 contains data and results for the summer M1 propellant burn tests.

Table C-1. Analytical data and results for June samples, M45 propellant tests.

Sample ID # 08FRA-S-	Sample Description	<2-mm (g)	>2-mm (g)	NG (mg/kg)	NG (mg)
Propellant Burn Soil Samples					
01	Core#1 Frozen Soil Burn Point (GOS*)	17		2,500	42
02	Core#2 Frozen Soil Burn Point (GOS)	16		1,200	19
03	Core#3 Frozen Soil Burn Point (GOS)	19		1,200	22
04	Core#4 Frozen Soil Burn Point (no GOS)	16		690	11
05	Core#5 Frozen Soil Burn Point (no GOS)	18		340	6.0
06	Core#6 Frozen Soil Burn Point (no GOS)	15		38	0.56
07 Lab Rep A	Bulk Sample at Frozen Soil Burn Point (GOS)	2,600	72	1,000	2,600
07 Lab Rep B	Bulk Sample at Frozen Soil Burn Point (GOS)	2,600	72	1,016	2,600
07 Lab Rep C	Bulk Sample at Frozen Soil Burn Point (GOS)	2,600	72	960	2,500
07 mean	Bulk Sample at Frozen Soil Burn Point (GOS)	2,600	72	990	2,600
08 Lab Rep A	55-Incr. (0.5 m r.) around Frozen Soil Burn Pt.	830	38	220	180
08 Lab Rep B	55-Incr. (0.5 m r.) around Frozen Soil Burn Pt.	830	38	230	190
08 Lab Rep C	55-Incr. (0.5 m r.) around Frozen Soil Burn Pt.	830	38	220	180
08 mean	55-Incr. (0.5 m r.) around Frozen Soil Burn Pt.	830	38	220	190
09	Core#1 Snow Burn Point (brown GOS)	17		2,800	45
10	Core#2 Snow Burn Point (brown GOS)	18		1,400	24
11	Core#3 Snow Burn Point (black GOS)	17		1,300	21
12 Lab Rep A	Bulk Sample at Snow Burn Point (GOS)	4,600	570	3,200	15,000
12 Lab Rep B	Bulk Sample at Snow Burn Point (GOS)	4,600	570	3,000	14,000
12 Lab Rep C	Bulk Sample at Snow Burn Point (GOS)	4,600	570	3,200	15,000
12 mean	Bulk Sample at Snow Burn Point (GOS)	4,600	570	3,100	15,000
13 Lab Rep A	55-Incr. (0.5 m r.) around Snow Burn Point	960	43	380	370
13 Lab Rep B	55-Incr. (0.5 m r.) around Snow Burn Point	960	43	380	370
13 Lab Rep C	55-Incr. (0.5 m r.) around Snow Burn Point	960	43	394	380
13 mean	55-Incr. (0.5 m r.) around Snow Burn Point	960	43	385	370

Sample ID # 08FRA-S-	Sample Description	No. of Grains	Grain Mass (mg)	NG (mg)
Propellant Grains from Soil Cores				
01 P	Grains from Core#1 Frozen Soil Burn Point	370	1,500	84
02 P	Grains from Core#2 Frozen Soil Burn Point	350	1,400	84
03 P	Grains from Core#3 Frozen Soil Burn Point	260	1,000	59
09 P	Grains from Core#1 Snow Burn Point	330	1,300	64
10 P	Grains from Core#2 Snow Burn Point	140	560	37
11 P	Grains from Core#3 Snow Burn Point	270	1,100	67
*GOS: Propellant grains on surface				

Table C-2. Analytical data and results for July samples, M45 propellant burn tests.

Sample ID # 08-FRA-	Sample Description/ Depth	<2-mm (g)	NG (mg/kg)	NG (mg)
July Propellant Profiles after removing top 2.5 cm				
Snow - Center of pit				
64	0–2 cm	26	23	0.60
65	2–4 cm	34	<0.1	
66	4–6 cm	33	<0.1	
67	6–8 cm	29	<0.1	
68	8–10 cm	19	<0.1	
69	10–12 cm	39	<0.1	
70	12–14 cm	28	<0.1	
Snow - North Wall of pit				
71	0–2 cm	33	180	5.8
72	2–4 cm	28	46	1.3
73	4–6 cm	34	9.0	0.30
74	6–8 cm	30	<0.1	
75	8–10 cm	46	<0.1	
76	10–12 cm	42	<0.1	
77	12–14 cm	43	<0.1	
78	14–16 cm	16	6.3	0.10
Frozen Soil Burn - center of pit				
79	0–2 cm	43	52	2.2
80	2–4 cm	42	<0.1	
81	4–6 cm	34	<0.1	
82	6–8 cm	36	<0.1	
83	8–10 cm	29	<0.1	
84	10–12 cm	25	0.29	0.01
Additional soil with grains at burn points				
85	Snow Burn Point: No. side mass	180	2,500	460
86	Snow Burn Points: Periphery	260	3,400	910
87	Frozen Soil: East side	280	3,400	950

Table C-2 (cont'd). Analytical data and results for July samples, M45 propellant burn tests.

Sample ID# 08-FRA-S-	Sample Description/ Depth	<2-mm (g)	NG (mg/Kg)	NG (mg)	Number of Incrs.	NG (mg) in Annulus†
July Multi-increment Samples around Burn Points						
56	1.0–1.5, Rep 1, Frozen Soil Burn Pt.	1,200	<0.1		26	<10
57	1.0–1.5, Rep 2, Frozen Soil Burn Pt.	1,200	<0.1		26	<10
58	1.0–1.5, Rep 1, Snow Burn Pt.	1,100	3.7	3.9	20	430
59	1.0–1.5, Rep 2, Snow Burn Pt.	990	6.8	6.8	22	680
60 Lab Rep A	0.5–1.0, Rep 1, Frozen Soil Burn Pt.	850	4.2	3.6	21	230
60 Lab Rep B	0.5–1.0, Rep 1, Frozen Soil Burn Pt.	850	4.0	3.4	21	210
60 Lab Rep C	0.5–1.0, Rep 1, Frozen Soil Burn Pt.	850	4.7	4.0	21	250
60 mean	0.5–1.0, Rep 1, Frozen Soil Burn Pt.	850	4.3	3.6	21	230
61	0.5–1.0, Rep 2, Frozen Soil Burn Pt.	930	0.97	0.90	23	52
62	0.5–1.0, Rep 1, Snow Burn Pt.	780	45	35	25	1,900
63	0.5–1.0, Rep 2, Snow Burn Pt.	870	52	45	25	2,400

†Estimated from mass of NG found and the area represented in each multi-increment sample (mg/cm^2) and the total area of the annulus.

Table C-3. Analytical data and results for August samples, M1 propellant burn tests.

Sample ID # 08-DTA-S-	Sample Description	Fraction Mass (g)	2,4-DNT (mg/kg)	2,6-DNT (mg/kg)	2,4-DNT (mg)	2,6-DNT (mg)	Total DNT Mass (mg)
Less than 2 mm Fraction of Sample							
Background							
165A	Background (Different bag)	430	3.6	0.16	1.6	0.070	1.6
165B	Background (Different bag)	430	3.6	0.14	1.6	0.060	1.6
Dry burn							
166A	Dry burn - Sand plume	2,300	880	38	2,000	88	2,000
166B	Dry burn - Sand plume	2,300	880	39	2,000	91	2,100
164A	Dry burn - Subsurface	2,180	150	5.9	330	13	340
164B	Dry burn - Subsurface	2,180	150	6.1	330	13	340
168A	Dry burn-ann. scoop width	740	13	0.3	9.6	0.22	9.8
168B	Dry burn-ann. scoop width	740	11	0.3	8.2	0.22	8.4
Wet burn							
169A	Wet burn - Sand plume	1,400	1,400	52	1,900	71	2,000
169B	Wet burn - Sand plume	1,400	1,400	50	1,900	69	1,900
167A	Wet burn - Subsurface	1,700	380	16	660	28	690
167B	Wet burn - Subsurface	1,700	370	16	640	28	670
163A	Wet burn- ann. scoop width	480	25	0.60	12	0.29	12
163B	Wet burn- ann. scoop width	480	24	0.40	12	0.19	12
Greater than 2 mm Fraction of Sample							
Background							
165R	Oversize of Sample 165	340	1.1	<0.02	0.37	<0.01	0.37
Dry burn							
166R	Oversize of Sample 166	1,900	250	13	490	25	510
164R	Oversize of Sample 164	1,600	48	1.8	77	2.9	80
168R	Oversize of Sample 168	590	9.1	0.40	5.3	0.23	5.6
Wet burn							
169R	Oversize of Sample 169	1,300	300	16	410	21	430
167R	Oversize of Sample 167	1,400	99	4.5	140	6.4	150
163R	Oversize of Sample 163	390	6.4	0.10	2.5	0.04	2.5

Appendix D: Analysis Results of Unburned Propellant Grains Recovered after M45 Tests.

Table D- 1. Mass (mg) of individual M45 double-base grains and collective mass of 20 grains.

Grain #	Mass (mg)	Grain #	Mass (mg)
1	4.1	11	4.1
2	3.5	12	4.2
3	4.0	13	3.6
4	4.3	14	3.9
5	3.6	15	3.6
6	3.4	16	3.2
7	4.0	17	4.2
8	4.1	18	3.4
9	3.4	19	4.2
10	4.0	20	3.6
Statistics for Mass (mg) Minimum: 3.2 Maximum: 4.3 Mass of 20 grains: 76 Mean mass: 3.8			

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14. ABSTRACT

Military live-fire training missions utilizing mortars and howitzers frequently generate excess propellant charges. Disposal of this propellant is often done on-site and is referred to as expedient disposal. Investigations into energetics residues resulting from expedient disposal of propellants began in 2002 with the collection of residues inside and outside a propellant burn structure. These residues contained very high concentrations of 2,4-Dinitrotoluene, an indication that the burning process was not complete. Other informal tests were conducted, indicating the same results. In 2006 and 2008, a series of tests were conducted on snow using propellants from various mortar cartridges. In one test, 10 charges of mortar propellant were burned on snow and the residues collected and analyzed. Over 15% of the original nitroglycerin content was recovered. In 2008, two series of tests were conducted, one involving winter disposal of mortar propellants, the other summer disposal of howitzer propellants. These tests, conducted under controlled conditions, indicate that the environmental setting and climatic conditions can influence the efficiency of expedient propellant disposal by three orders of magnitude.

15. SUBJECT TERMS
Propellants, energetics, residues, artillery, mortars, howitzers, firing points, expedient disposal, snow, multi-increment sampling

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